DETERMINATION OF EXPLOSION PARAMETERS OF HYDROGEN-AIR MIXTURES IN CLOSED VESSEL

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ABSTRACT

Hydrogen has been proposed as a potential fuel to replace fossil fuels in consideration to reduce carbon emissions. This paper presents experimental data on the characteristics of hydrogen-air explosion in air mixture using 20-L sphere. This data includes the maximum explosion pressure, deflagration index, and the maximum rate of pressure rise. Methods and equations are available to estimate these parameters.

The experimental maximum explosion pressure agrees with the theoretical value estimated using a chemical equilibrium program if the concentration of hydrogen is from 10 % to 75% in air but not close to the flammable limits. Therefore, the maximum pressure can be estimated conventionally by the equilibrium program regardless of the size of the explosion vessel.

Deflagration index for mixture of hydrogen in air, even if normalized by the cube root of the number of vessels explosion, is shown to be sensitive to the vessel volume. The fraction of burnt gas just before the flame contacts the wall has a dominant effect on the deflagration index (Crowl, 2001). From experimental data the deflagration index of hydrogen explosion in 20 L is 212.54 bar.m / sec. The maximum explosion pressure is 2.8 bar at the amount of 22% hydrogen in air and the maximum rate of increase in pressure is 783 bar. Experimental values are different from the theoretical value because there is an error during the experiment run. So, improvements need to be done to get better data experimental procedures in the future.

MENGENALPASTI PARAMETER LETUPAN BAGI CAMPURAN HIDROGEN-UDARA DI DALAM BEKAS TERTUTUP

ABSTRAK

Hidrogen telah dicadangkan sebagai bahan api yang berpotensi untuk menggantikan bahan api fosil dalam pertimbangan untuk mengurangkan pelepasan karbon. Kertas ini membentangkan data eksperimen mengenai ciri-ciri letupan hidrogen udara di dalam campuran udara menggunakan sfera 20-L. Data ini termasuk tekanan letupan maksimum, indeks deflagrasi, dan kadar maksimum kenaikan tekanan. Kaedah dan persamaan telah disediakan untuk menganggarkan parameter ini.

Tekanan letupan maksimum eksperimen adalah sama dengan nilai teori yang telah dianggarkan menggunakan program keseimbangan kimia jika kepekatan hidrogen adalah daripada 10% kepada 75% dalam udara tetapi tidak terlalu dekat dengan had mudah terbakar. Oleh itu, tekanan maksimum boleh dianggarkan biasanya oleh program keseimbangan tanpa mengira saiz sfera

Indeks deflagrasi untuk campuran hidrogen di dalam udara, walaupun normal oleh akar kiub jumlah vesel letupan, ditunjukkan untuk menjadi sensitif kepada jumlah kapal. Nilai pecahan gas dibakar sejurus sebelum kenalan nyalaan dinding mempunyai kesan dominan terhadap indeks deflagrasi (Crowl, 2001). Daripada data eksperimen indeks deflagration dalam sebuah sfera 20 L adalah bernilai sebanyak 15.66 bar.m / sec. Tekanan letupan maksimum adalah 2.8 bar pada jumlah 22% hidrogen di dalam udara dan kadar maksimum kenaikan tekanan adalah 783 bar. Nilai eksperimen adalah berbeza daripada nilai teori kerana terdapat ralat semasa eksperimen di jalankan. Jadi, penambahbaikan perlu lah dilakukan untuk mendapat data eskperimen yang lebih baik pada masa akan datang.

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LIST OF SYMBOLS

P	Pressure
T	Time
V	Volume
K	Deflagration index
(dP/dt)	Rate of pressure rise
K_{St}	Deflagration index for dust
K_G	Deflagration index for gas
%	Percentage

LIST ABBREAVIATION

NFPA	National Fire Protection Association
ASTM	American Society for Testing and Material
FM	Factory Mutual System
UFL	Upper Flammability Limit
LFL	Lower Flammability Limit

CHAPTER I

INTRODUCTION

1.1 Background of Research

In new era, a great deal of effort has been dedicated to the continuing replacement of ordinary fossil fuels by new energy vectors, primarily because of the natural resources dry up and the simultaneous rapid increase of energy demands worldwide. Hydrogen is considered one of the most promising fuels for global use in the future, mainly because it is an energy-efficient, low-polluting and renewable fuel (Rigas et. al., 2005). On the other hand, aiming at environmental benefits such as combination of hydrogen with other gaseous fuels like natural gas is under consideration. One of the major issues affecting the approval of hydrogen for public use is the safety of hydrogen installations such as production and storage units, as well as its applications. Evaluation of hazards connected to the hydrogen storage facilities have been studied by Fotis Rigas & Spyros Sklavounos for many years to reveal potential accidents that hydrogen may yield under certain conditions. In their previous study, they examine the common hazards arising from hydrogen storage and distribution systems. Hazard analysis was performed based on Event Tree Analysis Method. Moreover, they also do a computational analysis on estimation of the dispersion resulting from liquefied hydrogen spills and this lead to a series of accident types that can cause a severe threat to the property and public safety.

In current works, theoretical and computational safety comparisons between hydrogen and other fuels, do not allow a clear point of view for the safest one to be concluded. Certainly, in the past, there were situation that hydrogen applications gave rise to severe accidents with significant economic and societal cost, show the need of improving safety measures wherever hydrogen is handled. Without doubt, the need for safety measures should be pointed out when failure prevention and public safety are concerned. In the context of combustion the characteristics that give high responsibility for explosion hazards in storage are reactivity and diffusivity of hydrogen. Because of these behaviors it is necessary to contribute in the planning and engineering design for storage, safety and performance in combustion engines and other applications (Law, 2004).

In order to increase the safety measure for handling of hydrogen in closed vessel the explosion parameters should be determined. There are three important parameters which are maximum explosion pressure, rate of pressure rise and deflagration index. Maximum explosion pressure can be defined as the highest value of pressure develops by a deflagration after a series of deflagration test is done over wide range of concentration. This value is normally used to design enclosure and to predict the severity of consequences. From this series of test the value of maximum rate of pressure also can be obtained. This value is needed in the calculation of deflagration index and also in predicted the violence of the explosion. The deflagration index will show how fast the pressure will rises following the ignition of dust of a known concentration in a container of a specific volume (20 liters). Besides that, deflagration index also will determine whether hydrogen can be classified as hazard class 1, 2 or 3. The higher the deflagration index, the more severe a dust explosion can be. Deflagration index, K can be calculated based on below equation:

$$K = \left(\frac{dp}{dt}\right)\mathrm{max} \times \sqrt[3]{V}$$

Where:

P	= pressure, bar
t	= time,s
V	= volume,m³
K	= deflagration index, bar.m/s
$\left(\frac{dp}{dt}\right)max$	= maximum rate of pressure rise, bar/s

1.2 Problem Statement

The characteristic of hydrogen such as wide flammability limit and lower source of ignition become the prime factors which contribute to the hazards of the hydrogen. So, these properties of hydrogen will cause threat to the property and public safety. If the explosion parameters in closed vessel cannot be determined it will definitely cause hazard explosion when there is source of ignition in the vessel. There are three parameters need to be studies which are maximum explosion pressure, deflagration index and maximum rate of pressure rise by determining these parameters, hazards risk of using hydrogen can be reduced.

1.3 Objectives of Research

The objectives of the study are to:

a) To investigate on the maximum pressure of explosion, P_{max} (bar)

b) To determine the maximum rate of pressure rise, dp/dt_{max} (bar/s)

c) To study on the deflagration index, K (bar.m/s)

1.4 Scope of Research

This experiment will run start from at the range of 2% by volume of hydrogen in air until the graph absolute pressure, P and rate of pressure rise, dP/dt against time is completely plot. The value of explosion pressure and rate of pressure rise of explosion can be determined during the course of single deflagration test. To get the value of maximum pressure, P_{max} and maximum rate of pressure rise series of test over wide range of concentration should be done. Maximum pressure can be defined as maximum explosion overpressure generated in the test chamber. From the data, the graph explosion pressure and explosion rate of pressure rise against hydrogen concentration will be plot. The value of maximum pressure and maximum rate of pressure rise then will be determined from these graphs. Deflagration index then can be calculated by using the value obtains from the graph.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Explosion could be said as a phenomenon that can happen anywhere likes in the residential area, vehicles, shop lot and many others places but major explosion usually occurs in industries, especially the industries that use lots of chemicals that have a high potential to cause an explosion. This fatal incident not only happen now days but already started a long time before. Where ever explosion occurs it might be cause by the same factor. Every year there's the case of explosion that can be read in the newspapers or widely spread on the internet no matter it’s a minor or major explosion. On 17 August, 2009 after the case of large property loss, the insured and insurers of a hydroelectric power plant in North America became involved in subrogation to determine if the event could be characterized as an explosion. The subject insurance policy provided coverage for explosions, but excluded mechanical breakdowns (Martin et. al., 2000). Therefore, based on the case many researchers are tried to define what is the exactly meaning and the caused of the explosion to classified whether this case can be describe as the explosion or not. The researched done by Martin, Ali and Larry were based on analysis of the accident and describe the necessary characteristic of explosion. Further investigation have been done by many others researcher to find the parameters of the explosion so that safety precaution can be take to prevent any fatality.

2.2 Explosions

2.2.1 Definition

Word of explosion is defined by Webster as a large scale, rapid and spectacular expansion, outbreak, other upheaval. This means that the process occur when a pressure wave of finite amplitude is generated in air by a rapid release of energy. The different types of energy sources can generate pressure waves and thus can be classified as explosives based on the definition. Explosion also can be defined as a sudden expansion of matter into a much larger volume than it formerly occupied (Martin et. al., 2000). Based on the past researcher explosion does not require the passage of combustion wave through the exploding medium, whereas an explosive gas mixture must exist in order to have either a deflagration or detonation.

When vapors, dusts or gases mixed with the sufficient amount of air and ignited explosive combustion might happen (DeHann, 1991).

Based on another sources by Glassman (1977) has defined explosion is a term which corresponds to rapid heat discharge or in other word can be say as pressure rise. An explosive gas or gas mixture is one which will allow rapid energy release, as compared to most stable, low temperature reaction. Glassman also said that it is very regular to confuse between a pure explosion and detonation.

According to Saifol (2008) explosion also can be defined as an event in which energy is released over a sufficiently small period of time and in a sufficiently small volume to generate a pressure wave of finite amplitude traveling away from the source. This energy may have been originally stored in the system as chemical, nuclear, electrical, or pressure energy. However, the release is not considered to be explosive unless it rapid and concentrated enough to produce a pressure wave that can be heard (Saifol, 2008).

By considering the definition found in the safety code standards issued by National Fire Protection Association (NFPA) and the Factory Mutual System (FM) gives a different perspective in the definition of the explosion. National Fire Protection Association has defined the term of explosion as the bursting or rupture of an enclosure or a container due to the development of internal pressure from a deflagration. The word of enclosure can be defined as confined or partially confined volume while deflagration can be said as a propagation of a combustion zone at a velocity that is less than the speed of sound in the unreacted medium as stated in safety code standards (National Fire Protection Association, 2008).

In other words Factory Mutual System give a definition of an explosion as rapid transformation of potential physical or chemical energy into mechanical energy and involves the expansion of gases. Physical explosion originally from purely physical phenomena, such as rupture of boiler of pressurized container, or from interaction between water and molten or black liquor smelt while chemical explosion originate from a chemical reaction such as flammable vapor air explosion, a dust explosion, or detonation of an explosive or blasting agent. Deflagration is an exothermic reaction that propagates from the burning gases to the unreacted material by conduction, convection, and radiation (Factory Mutual System, 1999).

Therefore, both NFPA and FM concerned with the both effect on bursting and rupture and cause deflagration in their definition. NFPA does not include non combustion sources in their definition while FM regrouped it into two main categories which are physical and chemical. However, both standards require that the definition for explosion include the rapid expansion of gases (Martin et. al., 2000).

All researchers give their own definition of explosion but all of them concentrated on the same point which is increasing of energy release, rapidly increasing in pressure rise and also deflagration. Therefore, this is the keyword of the explosion.

2.2.2 Types of Explosion

2.2.2.1 Dust Explosion

Combustible materials are materials that are capable of burning in air. Most organic materials and metal and some of non metallic inorganic material will be burn or explode if they contact with sufficient ignition sources (Blair, 2003). Not all small particles will burn. For example, salt and baking soda, no matter how small of fine the powdered, it will not burn if they do not contain combustible material. Coffee creamer, on the other hand, will burn because it contains fat because fat can be categorized as inorganic material. Combustible dusts are can be manufactured or generated when solid combustible are handled or processed due to gradual reductions in the particle sizes and/or segregation of the particles.

National Fire Protection Association 654 (2006) has defines combustible dusts as a combustible particulate solid that presents a fire or deflagration hazard when suspended in air or some other oxidizing medium over a range of concentrations, regardless of particle size or shape. Awareness of combustible dust hazards is important to ensure employee safety, to ensure proper facility design, and to develop adequate operations and maintenance procedures (National Fire Protection Association, 2006).

They are many factors that influence the possibility and severity of dust explosion. Typically, for dust explosion to take place three conditions must be there which combustible dusts are is suspended, the dust is ignited and dust is confined such that damaging pressure and accumulate. Based on the researcher the finer the dust particle the more easily the dust oxidizes to give the higher potential for explosion to occur.

2.2.2.1.1Dust Explosion Pentagon

Fuel, ignition, oxygen, suspension, and confinement form the five sides of the dust explosion pentagon as shown in Figure 2.1. Like all other fires, a dust fire occurs when fuel is exposed to heat in the presence of oxygen. Removing any one of these elements of the fire triangle eliminates the possibility of a fire. A dust explosion requires the simultaneous presence of two additional elements which are dust dispersion and confinement. Confinement keeps dust particles in proximity after suspension to allowing sufficiently rapid heat transfer to continue propagation. Without confinement, a propagating explosion is not possible, though a large and very dangerous fireball may occur. Suspended dust burns more rapidly, and confinement allows for pressure buildup (Blair, 2003). Remove either the suspension or the confinement elements will terminate an explosion, though a fire may still occur, because the elements of the fire triangle (fuel, oxygen and ignition) exist.

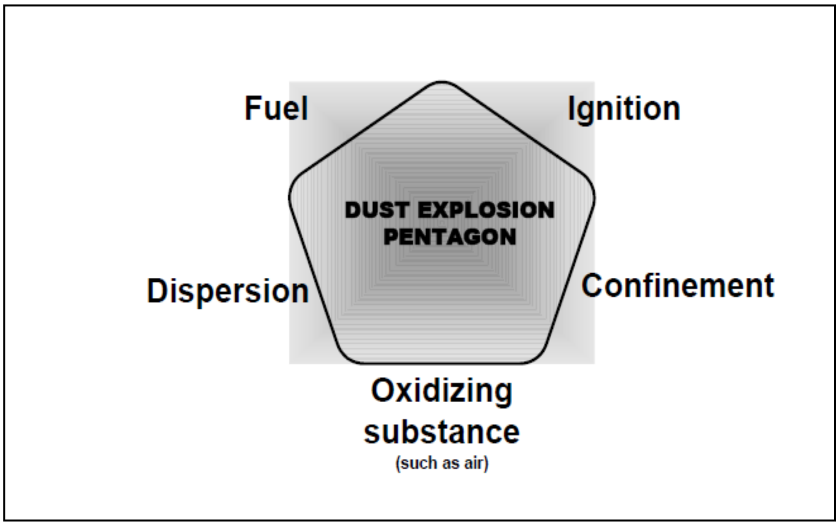

Figure 2.1 Dust Explosion Pentagon (Blair, 2003)

2.2.2.1.2Dust Explosion Characteristic

The relative explosibility of a given combustible dust is typically expressed using the deflagration index, K_{St} and depends on several factors. This index is determined experimentally by measuring how fast the pressure rises following the ignition of dust of a known concentration in a container of a specific volume (20 liters). The higher the K_{St}, the more severe a dust explosion can be. National Fire Protection Association 68 (2002) defines three dust hazard classes, used to indicate relative explosiveness. Class St-1 dusts have a K_{St} at or below 200 bar-m/sec, St-2 dust K_{St} values range from 201 to 300 and St-3 dusts have a K_{St} above 300 bar-m/sec. The following table shows the K_{St} values and hazard classes for some commonly known combustible dusts.